

1st Year Fluids - Impact of a Jet

Objective

To demonstrate the applicability of Newton's law of motion to a fluid. To investigate the effects of a jet flow on differently shaped targets, comparing theoretical predictions with actual measurements.

Theory

An example of the application of the momentum equation arises with the impact of jets and their subsequent deflection on targets of various shapes. In the experiments in the laboratory a vertical water jet is aimed at a target. The vertical force exerted on the target by the water is measured by placing weights on a weight pan until the force of the jet is matched.

By Newton's second law, momentum, force = rate of change of momentum:

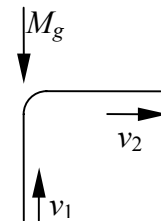
$$Mg = mv_1 - mv_2 = \rho Q(v_1 - v_2)$$

(where M is the mass on the weight pan, Q is the flow, g is acceleration due to gravity, ρ the density of the fluid and v_1 and v_2 are the initial and final velocities respectively).

Horizontal, 90° Deflector: After hitting the target the jet is deflected at 90° and no longer has any momentum in the y direction, hence the component of $v_2 = 0$. Resolving in the y -direction:

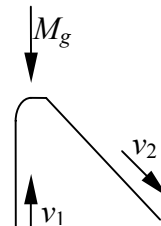
$$Mg = \rho Q(v_1 - v_2 \cos 90) = \rho Qv_1$$

as $Q = vA$ where A is the area of the jet, $Mg = \frac{\rho Q^2}{A}$



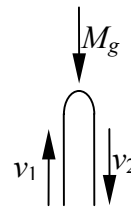
120° Deflector: Resolving in the y -direction:

$$Mg = \rho Q(v_1 - v_2 \cos 120) = \rho Q \left(\frac{Q}{A} - \left(-\frac{Q}{2A} \right) \right) = \frac{3\rho Q^2}{2A}$$



180° Deflector: The water returns in the same direction it has come, so:

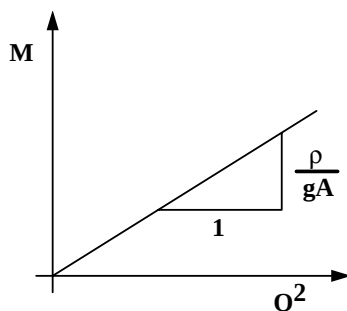
$$Mg = \rho Q(v_1 - v_2 \cos 180) = \rho Q \left(\frac{Q}{A} - \left(-\frac{Q}{A} \right) \right) = \frac{2\rho Q^2}{A}$$



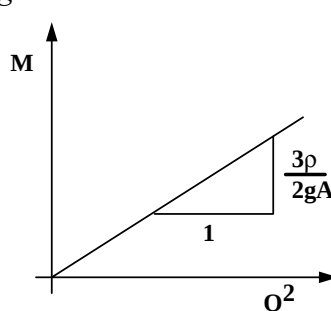
Plotting graphs of M against Q^2 for these three equations will give straight lines with the following gradients:

Horizontal, 90°, target gradient = $\frac{\rho}{gA}$, 120° target gradient = $\frac{3\rho}{2gA}$

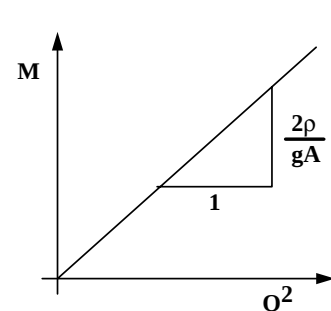
Hemispherical, 180° target gradient = $\frac{2\rho}{gA}$



Horizontal, 90°, Target



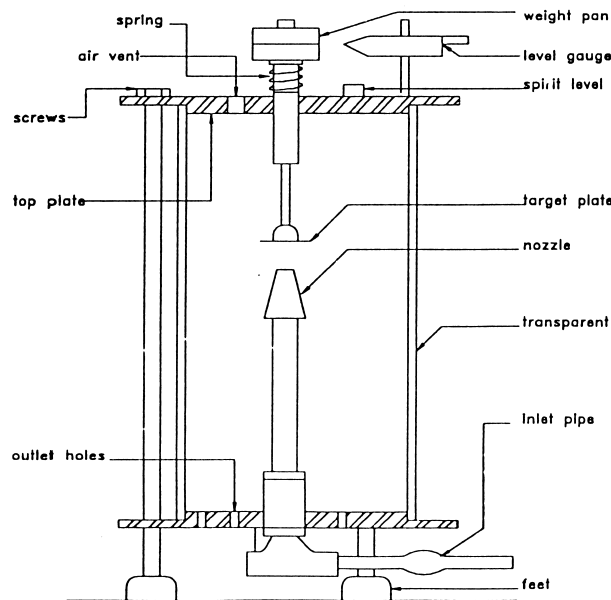
120° Target



Hemispherical Target

Apparatus set-up

- 1) Remove the top plate of the apparatus and the transparent casing.
- 2) Measure the nozzle diameter.
- 3) Screw the flat target onto the bar connected to the weight pan.
- 4) Reassemble the apparatus and place it in the bench channel.
- 5) Connect the apparatus hose to the water supply.
- 6) Level the base of the apparatus using the black feet.
- 7) Adjust the pointer so that it is level with the datum line on the weight pan - minimise friction in the spring by oscillating the weight pan.

**Method**

- 1) Place a 50g weight on the weight pan.
- 2) Turn on the power at the wall socket.
- 3) At the bench control panel, turn on the pump and open the red valve to turn on the water supply. When water supply is not in use, THE PUMP MUST BE SWITCHED OFF, otherwise it will burn out.
- 4) Adjust the flow rate using the red valve until the datum line on the weight pan is once again level with the pointer (nudge the pan to overcome friction in the spring).
- 5) Measure the flow by dropping the ball plug and measuring volume increase with time using the **upper** volume indicator on the side of the bench. Start the stopwatch when the level reaches zero.
- 6) Continue to add 50g weights, and repeat the process until you have ten readings.
- 7) Repeat the experiment using the 120° and hemi-spherical targets.

Results

nozzle diameter =	nozzle area $A =$	$g =$	$\rho =$
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Flat 90° Target

mass on pan M (kg)	volume (m^3)	time (s)	flow rate Q (m^3/s)	Q^2
0.050	0.005			
0.100	0.005			
0.150	0.010			
0.200	0.010			
0.250	0.010			
0.300	0.010			
0.350	0.015			
0.400	0.015			
0.450	0.015			
0.500	0.015			

120° Target

mass M (kg)	volume (m^3)	time (s)	Q (m^3/s)	Q^2
0.050	0.005			
0.100	0.005			
0.150	0.010			
0.200	0.010			
0.250	0.010			
0.300	0.010			
0.350	0.015			
0.400	0.015			
0.450	0.015			
0.500	0.015			

Hemispherical 180° target

mass M (kg)	volume (m^3)	time (s)	Q (m^3/s)	Q^2
0.050	0.005			
0.100	0.005			
0.150	0.010			
0.200	0.010			
0.250	0.010			
0.300	0.010			
0.350	0.015			
0.400	0.015			
0.450	0.015			
0.500	0.015			

Analysis

- 1) On the same graph, plot M against Q^2 for each target and find the experimental gradient of each curve.
- 2) Calculate the theoretical gradients.
- 3) Compare the experimental with the theoretical in the form of a percentage error and summarise the results below:

	experimental	theoretical	% error
flat target			
120° target			
hemispherical target			

- 4) Make some critical assessment of the apparatus discussing any problems encountered.

- 5) What are the likely sources of error and of what magnitude are these errors?

